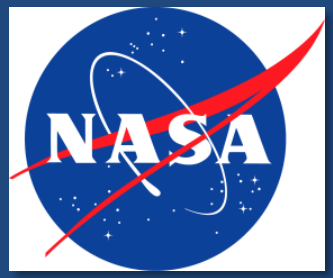
The Application of SBG-Class Observations to Monitor Volcanic Gas and Aerosol Plumes in Hawaii

Vincent J. Realmuto
David R. Thompson
Jet Propulsion Laboratory,
California Institute of Technology

HyspIRI/SBG 2018 Science Workshop



Contributors

Mike Abrams	Jet Propulsion Laboratory/ California Institute of Technology
Elsa Abbott	Jet Propulsion Laboratory/ California Institute of Technology
Steven Businger	University of Hawaii – Manoa
Tamar Elias	USGS - Hawaiian Volcano Observatory
Lacey Holland	University of Hawaii – Manoa
Keith Horton	FlySpec Incorporated
Florian Schwandner	University of California – Los Angeles
Howard Tan	Jet Propulsion Laboratory/ California Institute of Technology

Kīlauea Airborne Science Campaigns Jan – March 2017, Jan – Feb 2018

MODIS/ASTER Airborne Simulator (MASTER) TIR Observations to Map SO_2 Emissions at Summit of Kīlauea

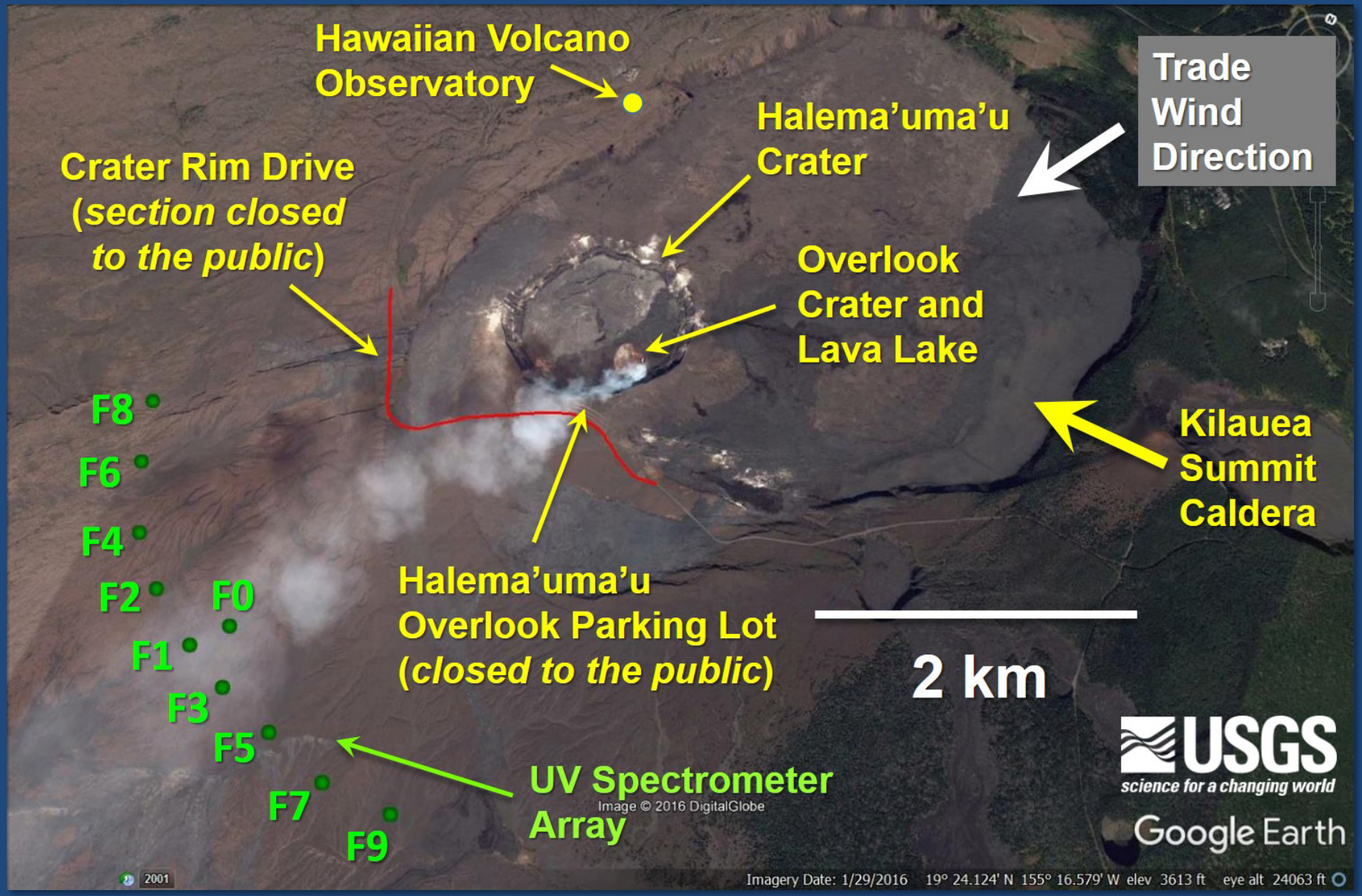
Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) VSWIR Observations to Map Changes in Optical Depth Related to SO_4 Aerosols

In 2018 - Hyperspectral Thermal Emission Spectrometer (HyTES) to Map SO_2 and SO_4 Aerosols

Cockpit of ER-2

Photo Courtesy of Stu Broce

Kīlauea Summit: Location Map



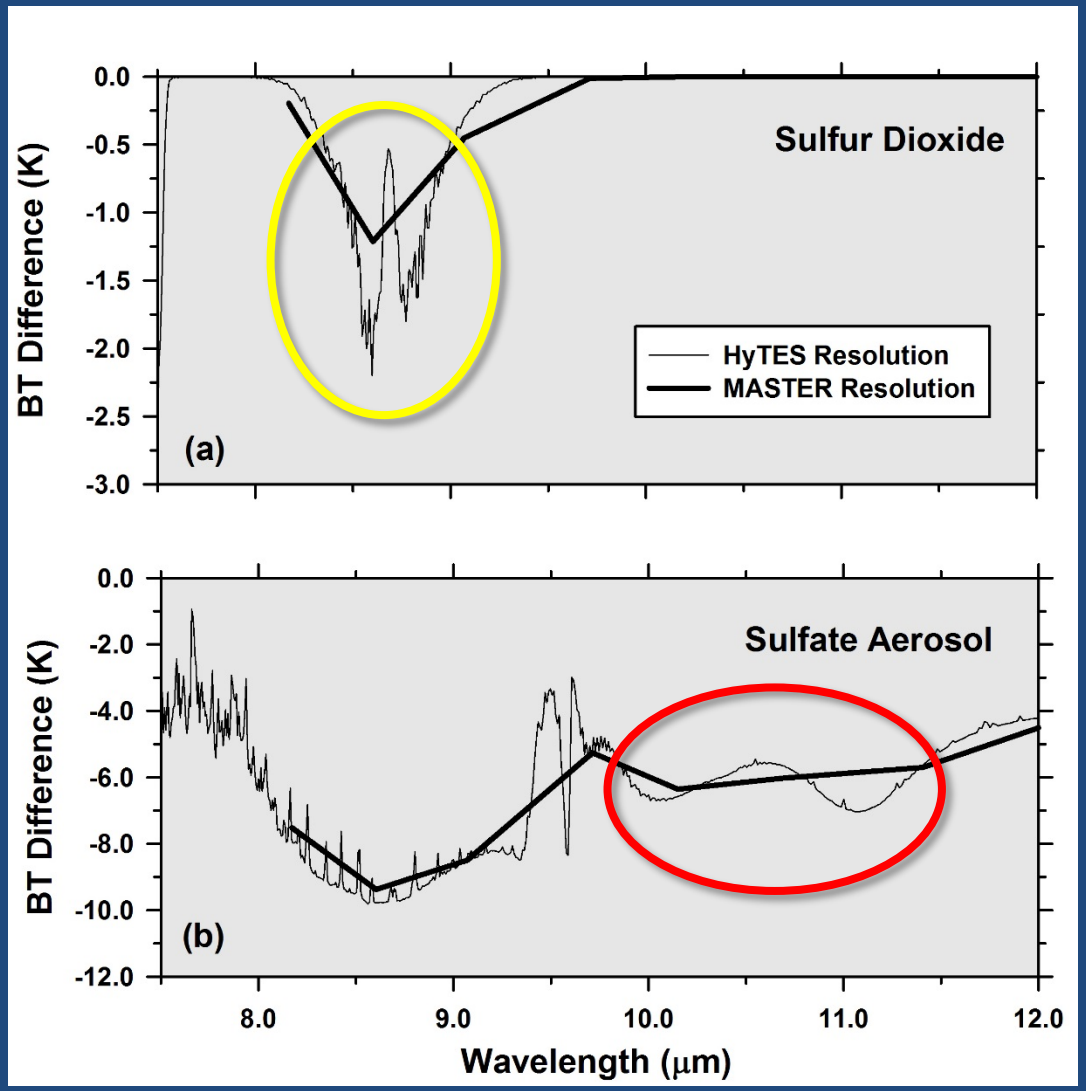
HyTES Deployment in 2018 Enables Unique Identification of Plume Components

MASTER Resolution

- Spectra of SO_2 and SO_4 are Similar
- Broad Absorption Centered near 8.7 μm

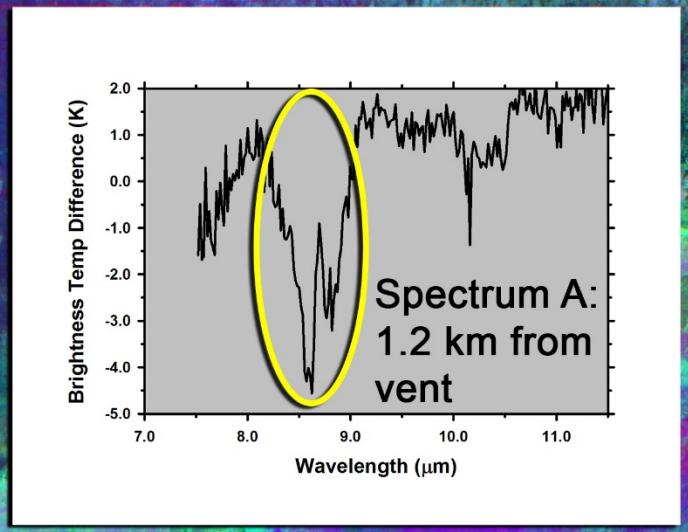
HyTES Resolution

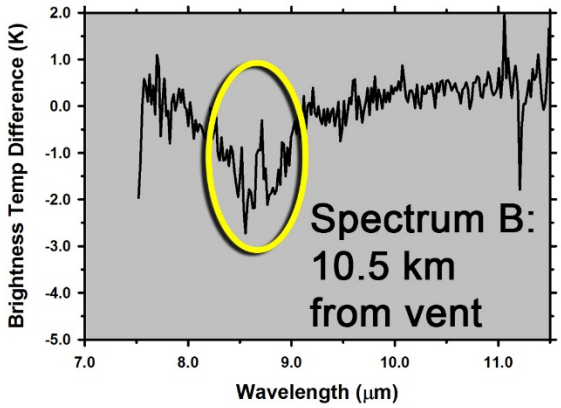
- Resolves "Doublet" in SO_2 Spectrum
- Detect SO_4 Absorption Features at 10 and 11 μm



HyTES Brightness Temperature Difference Spectra

Kilauea Volcano
2018-01-18
21:15 UTC (11:15 HST)





5 km

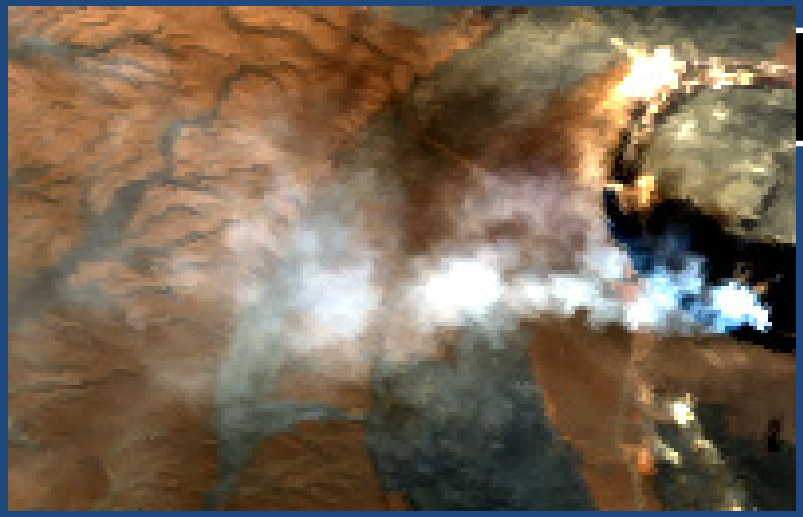
- Imaging Spectroscopy: Fine spectral resolution of HyTES (0.02 μm) enables unique identification of SO_2
- Spectrum A indicates stronger SO_2 absorption than Spectrum B
- Absence of SO_4 Spectral Features - Decrease in SO_2 result of dispersion, rather then conversion of SO_2 gas to SO_4 aerosols (conversion rate of ~8% /hr)

Optimal Estimation for Iterative Fitting of Surface and Atmospheric Spectra

Combined Parametric Models for Surface, Atmosphere, and Instrument Properties

Makes optimal, weighted use of *a priori* knowledge of instrument and domain

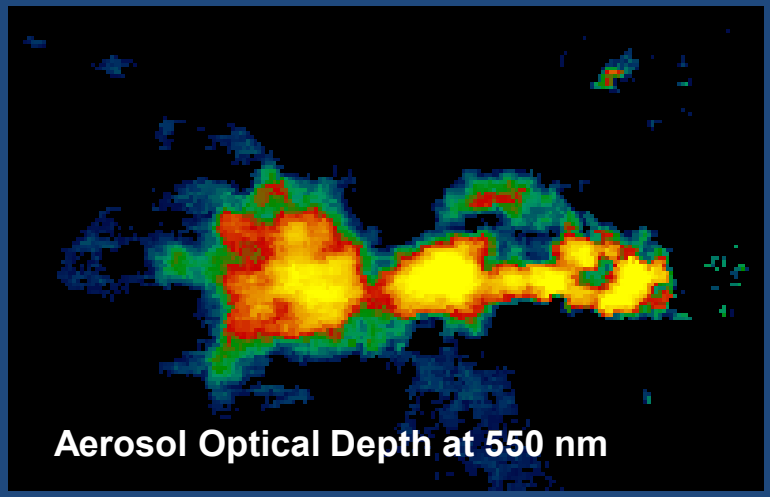
- Tropical Atmospheric Temperature/Humidity Profiles
- Scattering Aerosol Model
- Surface Reflectance Sampled In-Scene

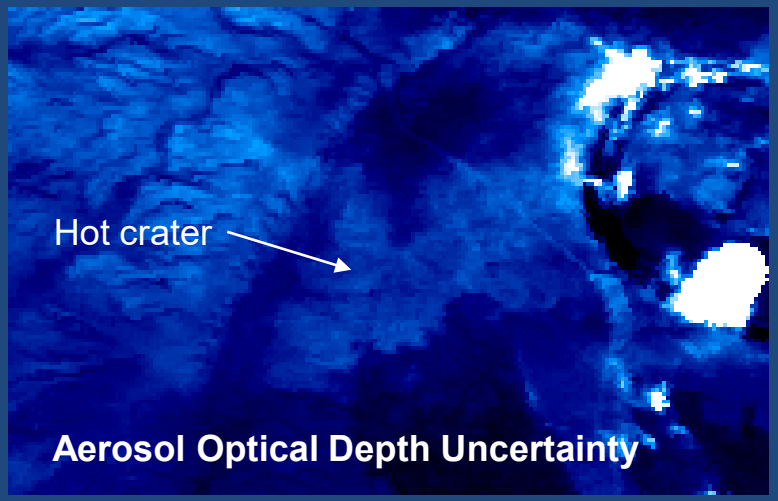


AVIRIS-C f170127t01p00r16 (subset, visible bands)

Combined estimate of H_2O vapor, AOD, surface reflectance and temperature

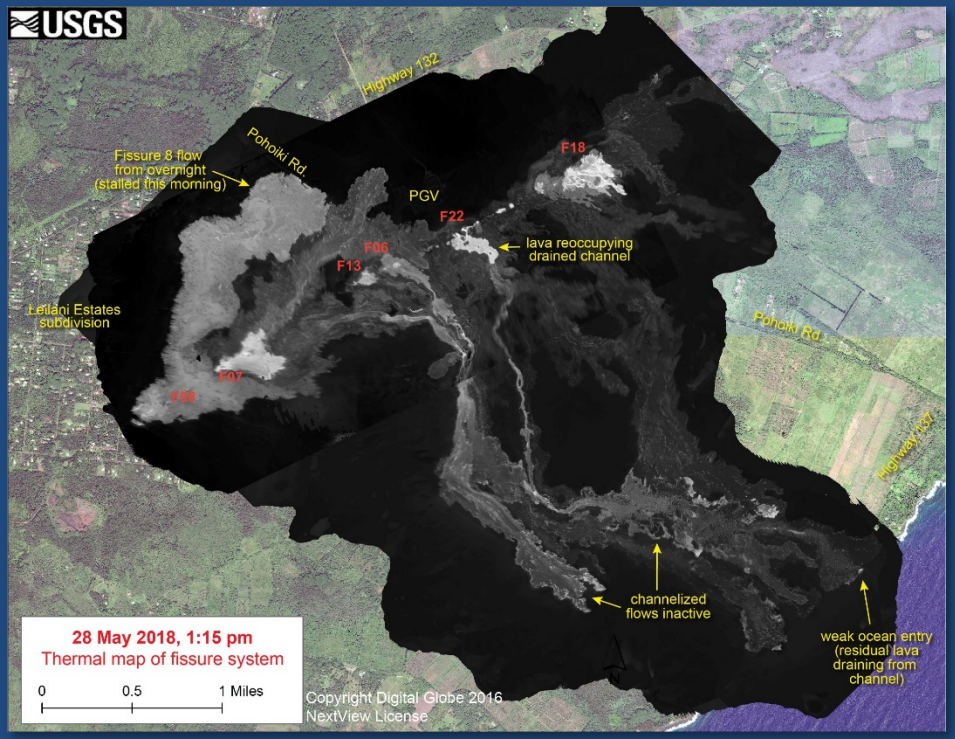
Down-wind Changes in AOD are Proxies for Formation of SO_4 Aerosols





Summit - Lower East Rift Zone (LERZ) Eruption

- Fissures open in Leilani Estates on May 3
- SO_2 emission rates in excess of 15,000 t/d
- Ash eruptions at Summit began May 15
- Ash plumes heights up to 10 km



500 + meters of subsidence at Summit

Towards an “Autonomous” Implementation of TIR-Based Retrieval Procedures for Terra, Aqua, SNPP, NOAA-20, ECOSTRESS, and SBG…

Plume Tracker Interactive Analysis Tool

- Radiative Transfer (RT) - Based Retrieval Procedures for Surface Temperature and Gas Concentration
- RT Processing is Computationally-Expensive

Autonomous Procedures Should Integrate Plumes Detection with Retrieval Algorithms

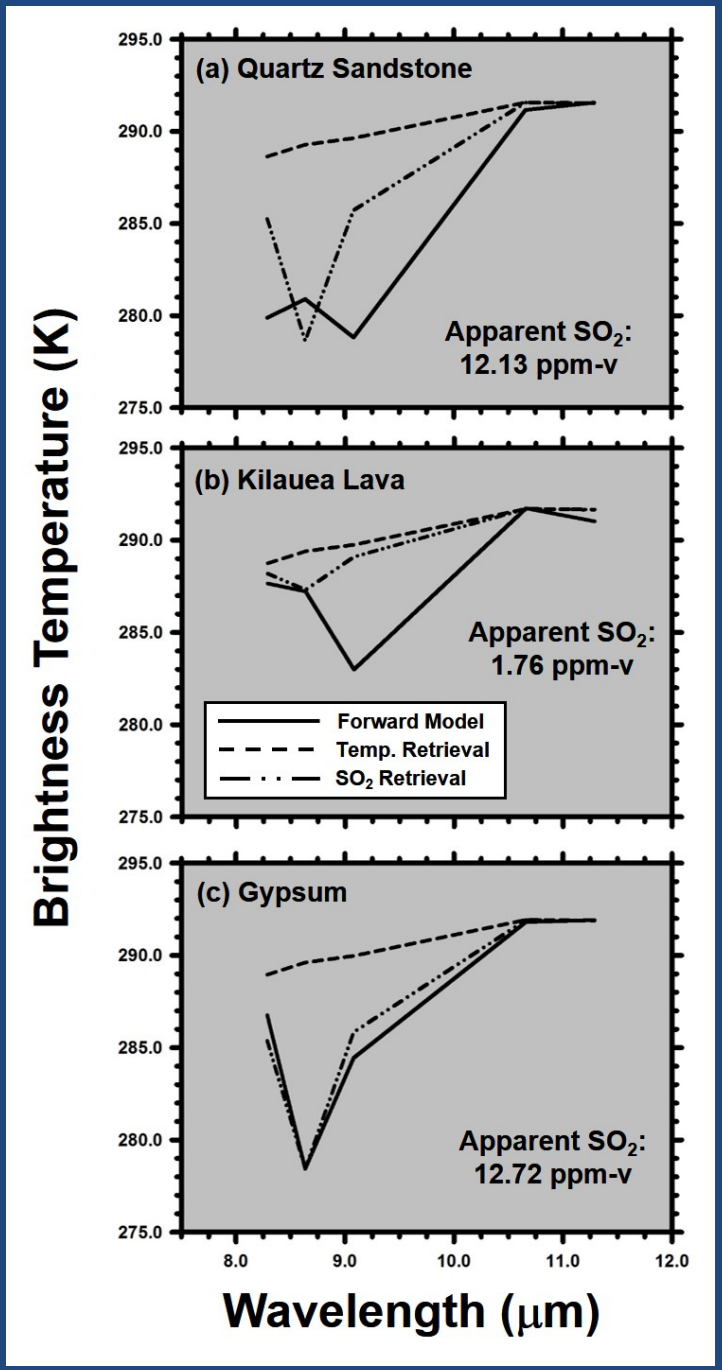
Surface Emissivity is a Confounding Factor for SO_2 Detection

Solid Lines: Forward model spectra generated for SO_2-free atmospheric profiles over simulated surface compositions of (a) quartz sandstone, (b) pahoehoe lava from Kilauea Volcano, and (c) gypsum

Dashed Lines: Attempts to fit the model spectra with Blackbody spectra ($\varepsilon = 1$) Accurate temperature estimates, but large misfit in Channels affected by SO_2 absorption

Broken Lines: SO_2 introduced as a free parameter to improve fit, with the penalty of false, or apparent, SO_2 detections.
The false detections are largest for (a) quartz sandstone and (c) gypsum, due to the overlap between emissivity minima and SO_2 absorption

As a rule, the assumption of blackbody emissivity for exposed (non-vegetated) surfaces will lead to false detections of SO_2

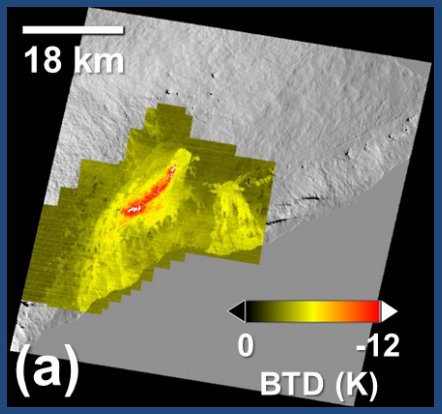


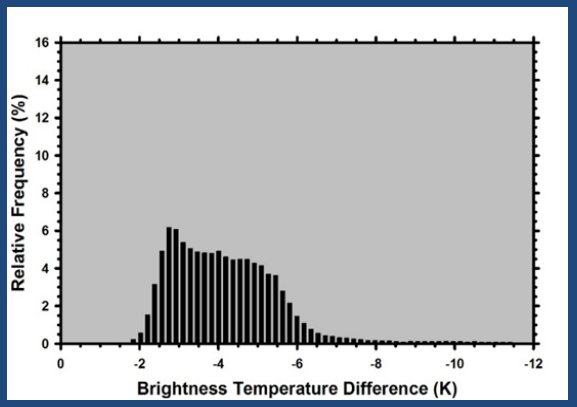
Plume Detections Improve with Corrections for Surface Emissivity and Atmospheric Effects

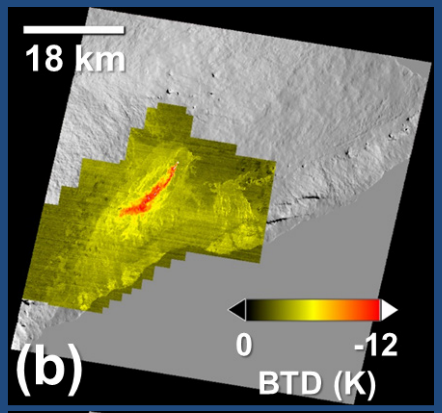
(a) Brightness Temperature Difference (BTD) in ASTER Channel 11
Plume is delineated by BTD of -12 K or larger
Emissivity effects result in BTD as large as -6 K outside of the plume. The histogram shows an offset of -2 K

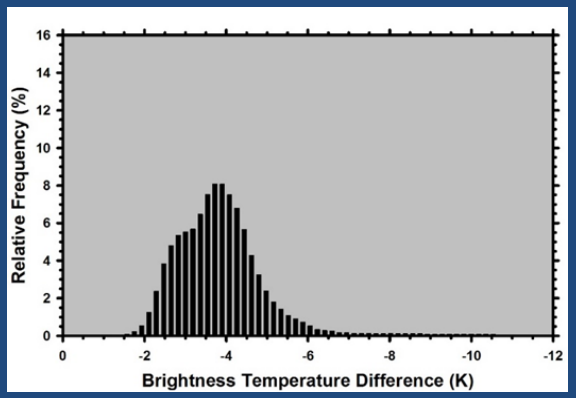
(b) BTD following a correction for surface emissivity
Emissivity effects have been suppressed, but the BTD remains non-zero outside of the plume
The histogram again shows an offset of -2 K

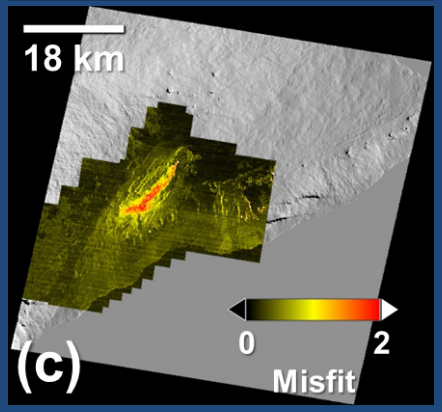
(c) Misfit map resulting from Plume Tracker-based retrievals of surface temperature, which take the emissivity and atmospheric effects into account
Plume is delineated by the highest misfit (≥ 1.0), and the misfit approaches zero outside of the plume
The histogram shows no offset, and over 90% of the misfit values are less than 0.5

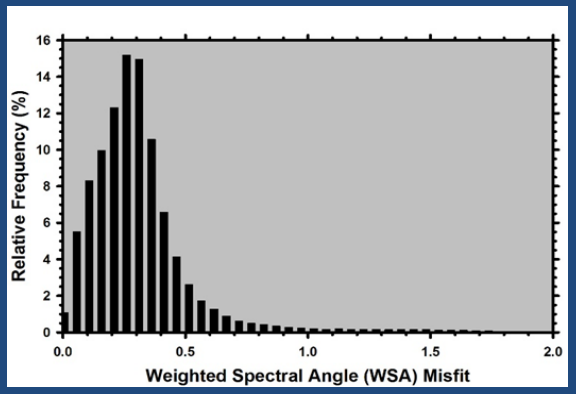




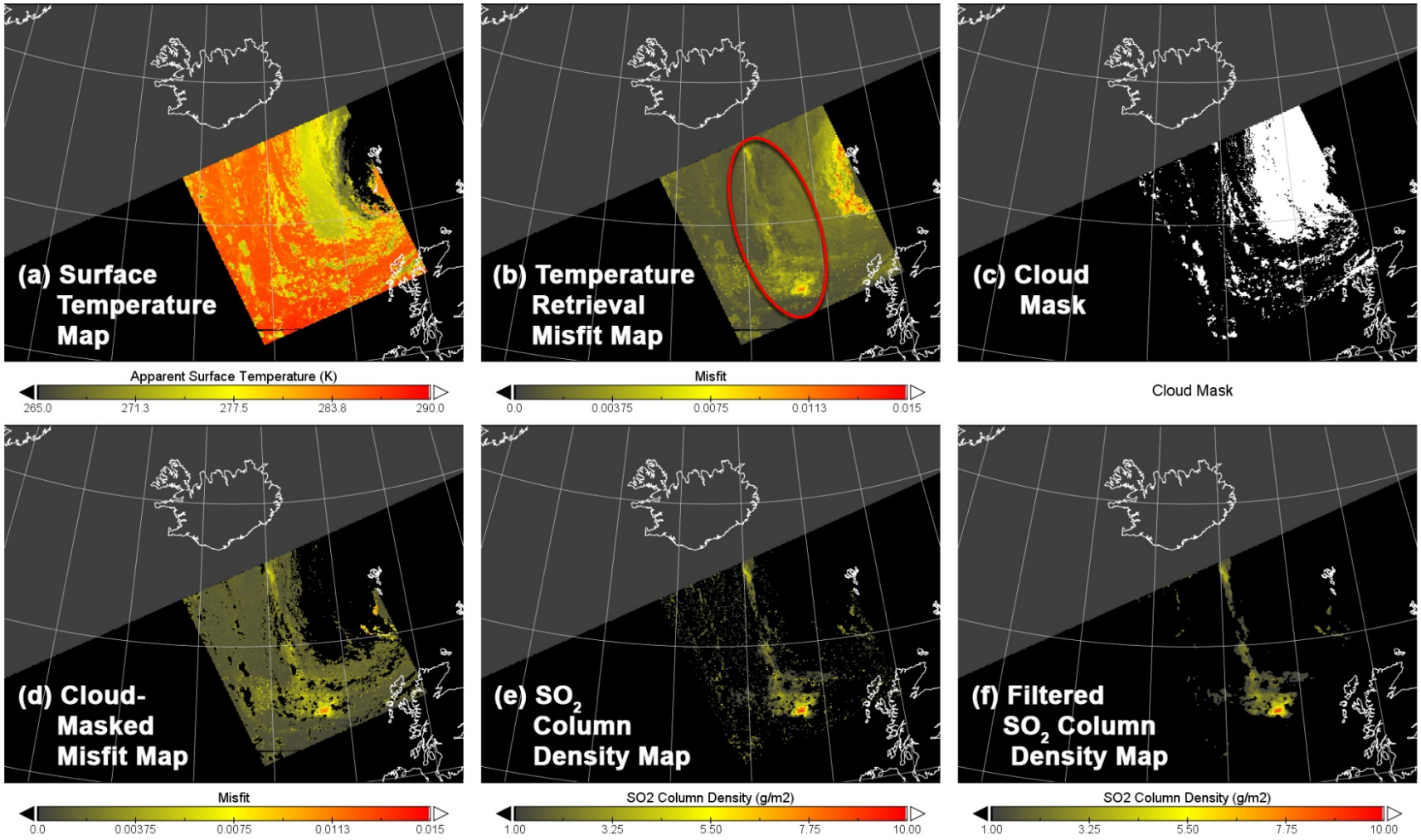








Bardarbunga Volcano (Iceland), 5 September 2014



a) Surface temperature estimation does not consider volcanic plumes or meteorological (met) clouds

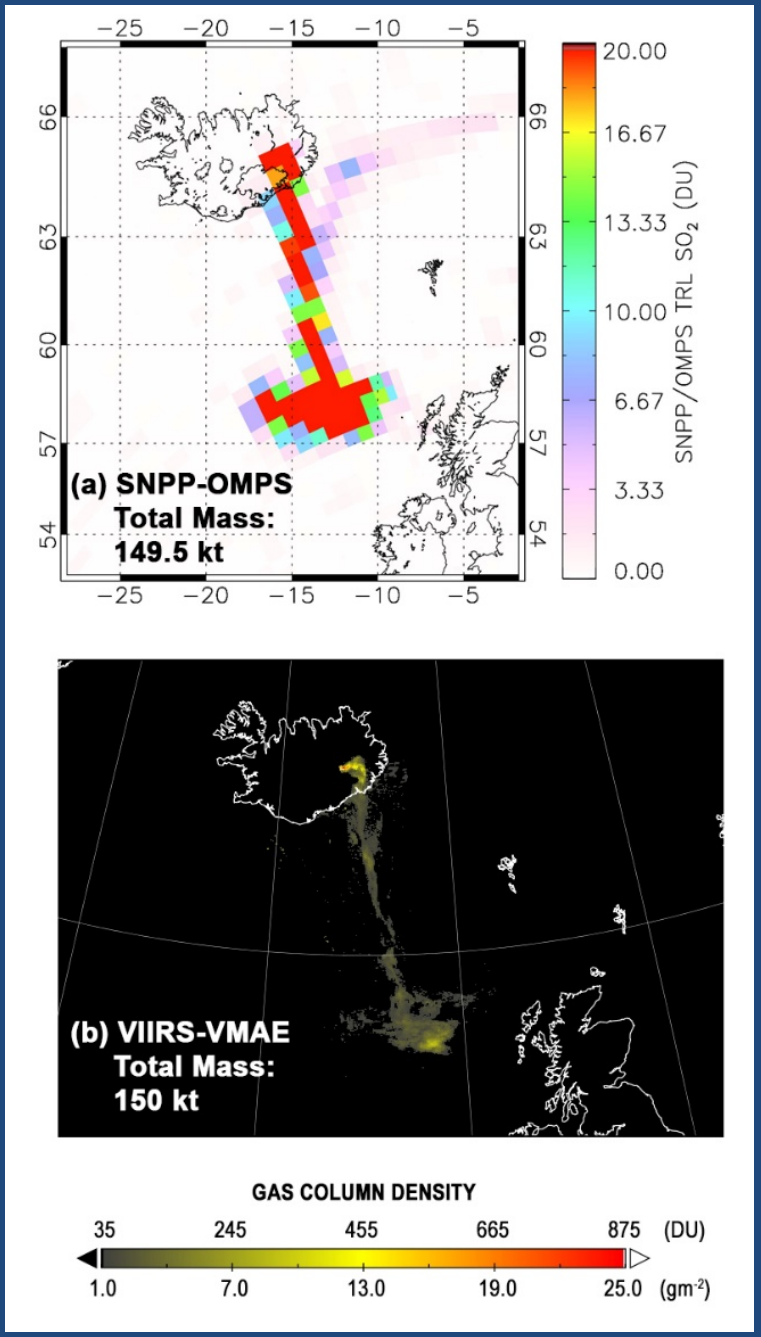
b) Misfit map shows the locations of plumes (red oval) and met clouds

c) Met clouds are identified by comparing surface temperature with air temperature at plume altitude

d) Combination of cloud mask and misfit map improves the discrimination of volcanic plumes

e) Estimation of SO_2 column density is confined to the locations, or pixels, identified by the masked misfit map

f) SO_2 map is filtered to minimize the “holes” corresponding to the locations of met clouds.



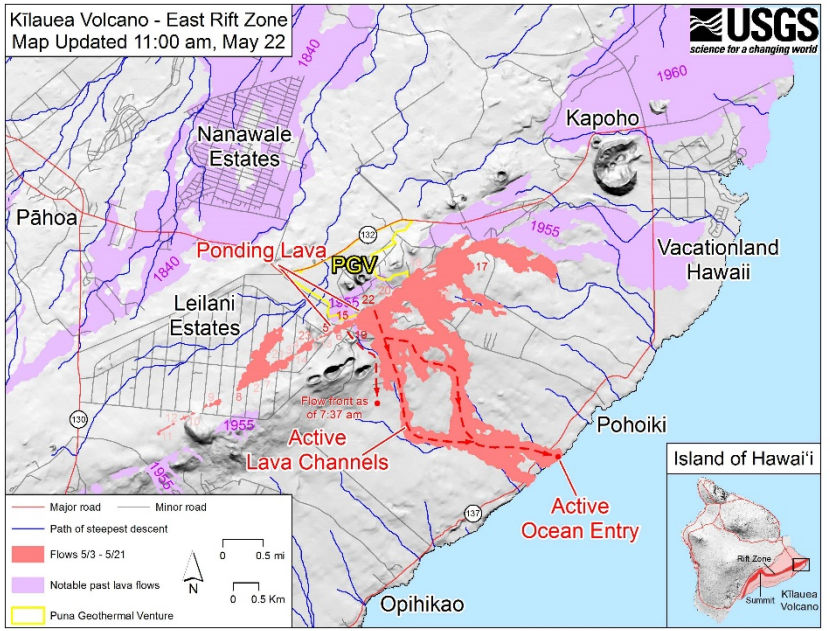
New Retrieval Procedure Successful

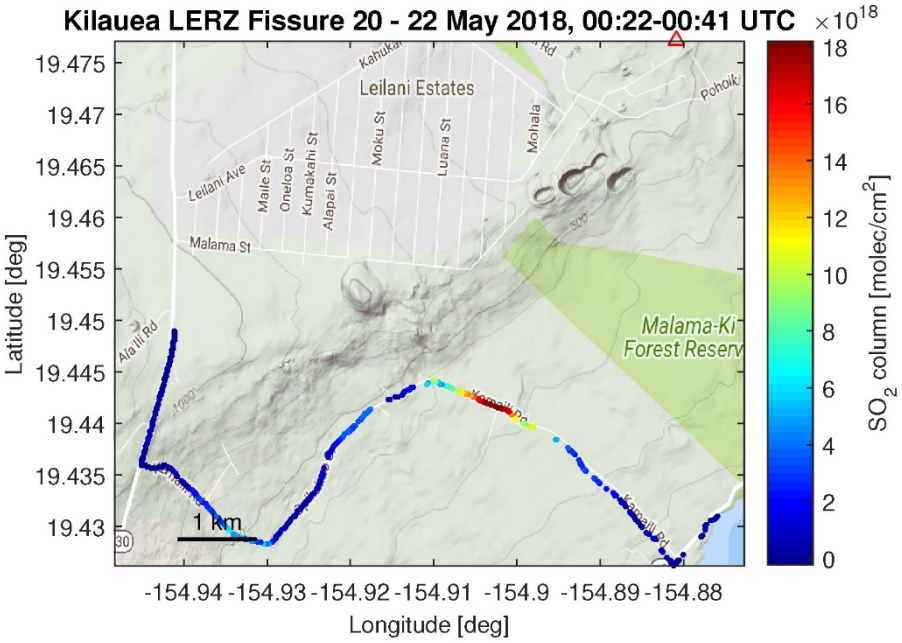
- Moderate to High SO_2 Concentrations
- Plume Altitude > 3 km ASL
- Arctic Atmospheric Environment (Atmosphere is Cool and Dry)

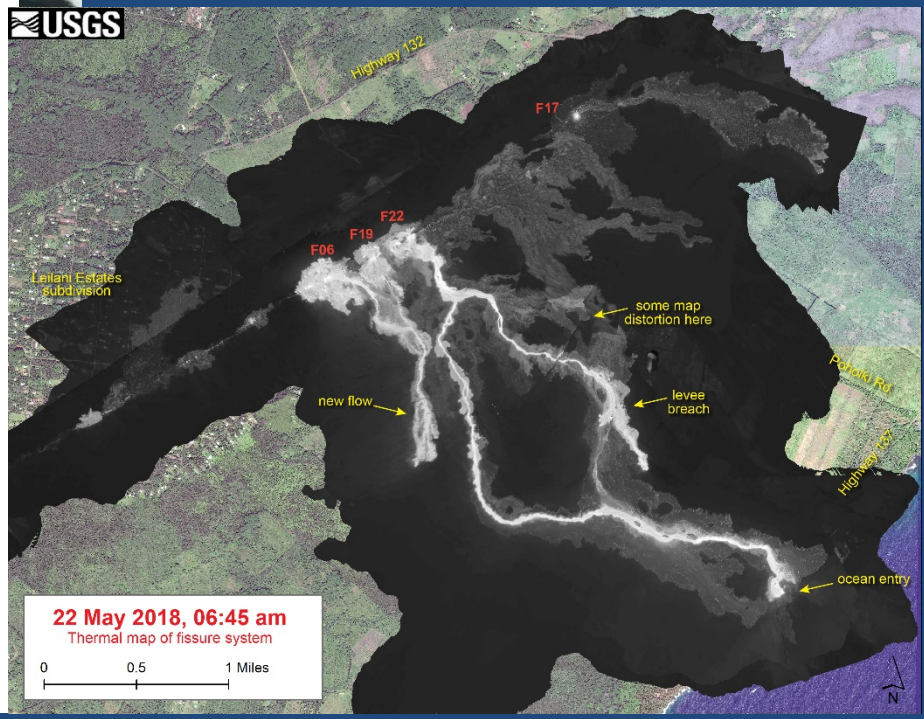
What About Low-lying Plumes in Tropical Environments?

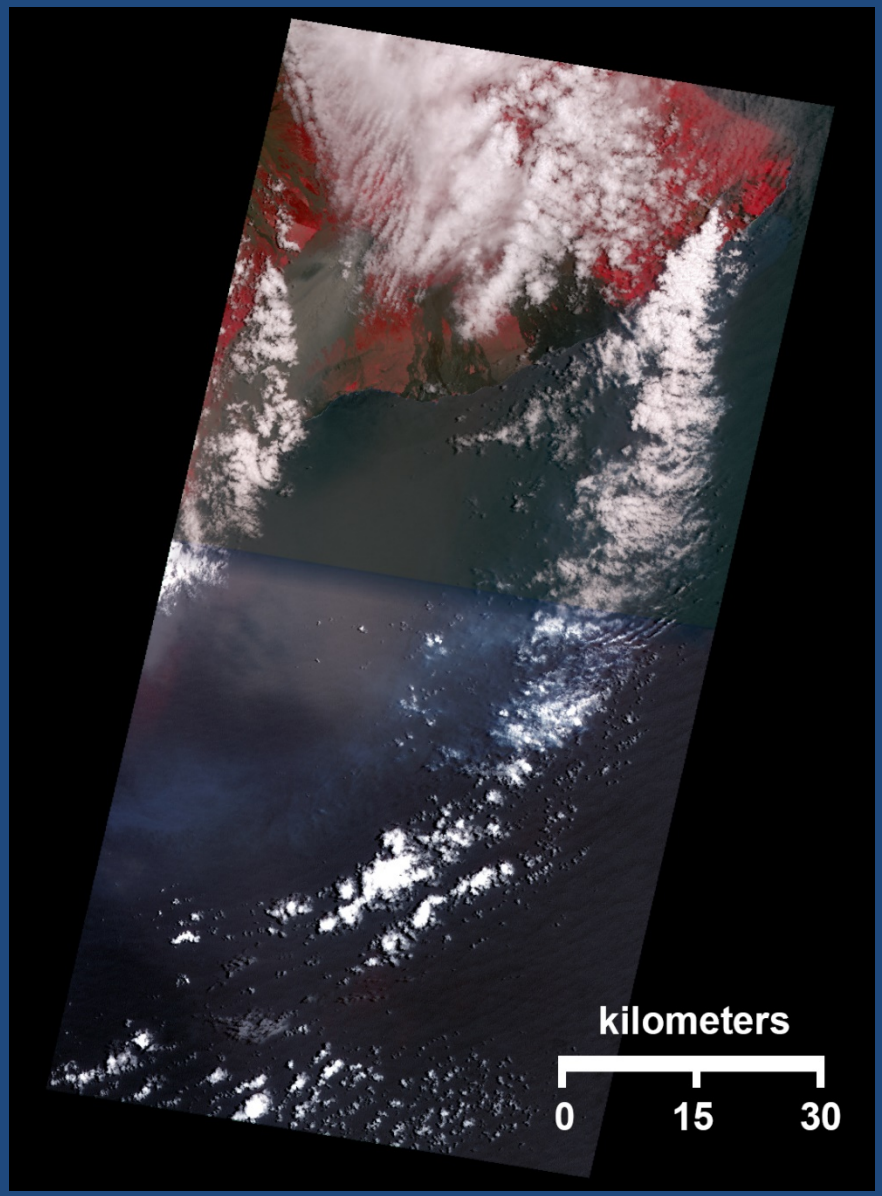
OMPS (UV) and VIIRS (TIR) Collocated on S-NPP and NOAA-20 Platforms Contemporaneous Retrievals of Total SO_2 Mass from S-NPP are in Excellent Agreement (149.5 vs. 150 kilotonnes)

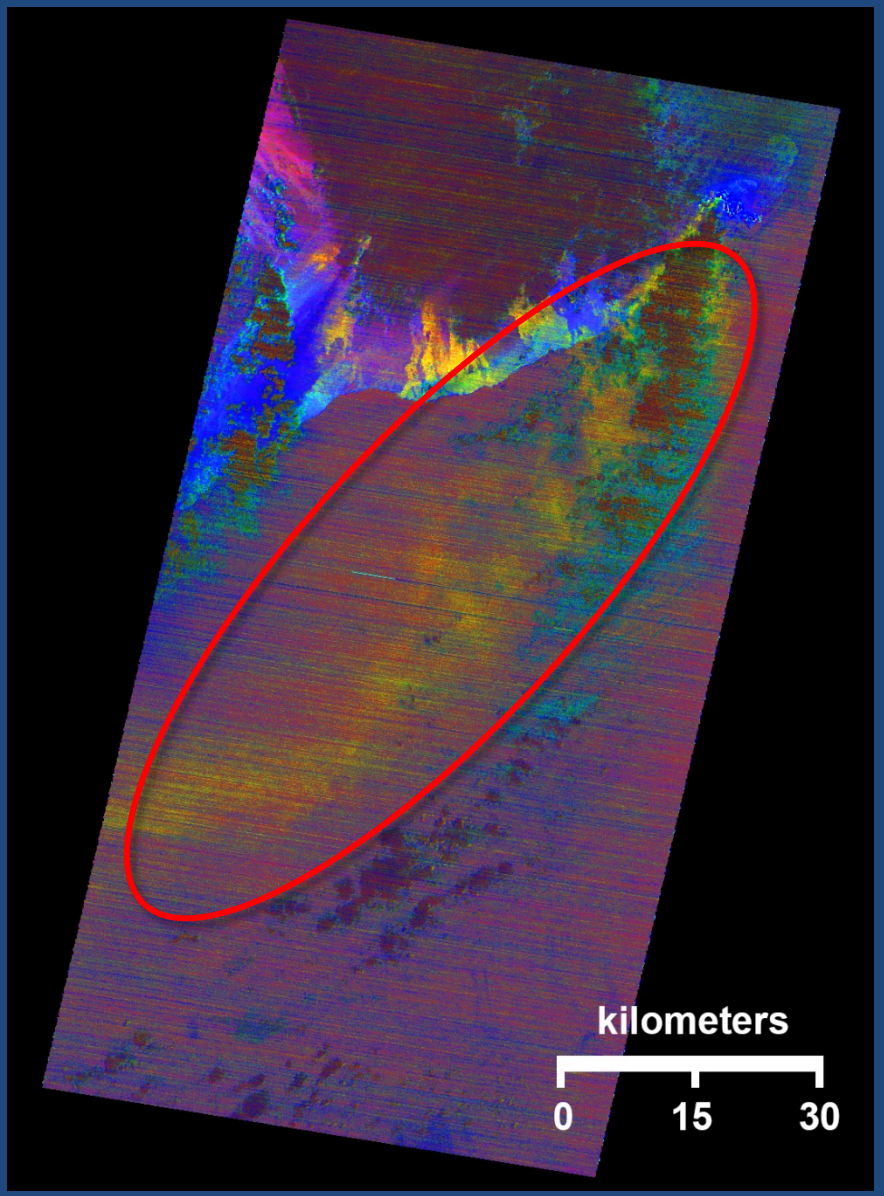

22 May 2018


Kīlauea Volcano - East Rift Zone
Map Updated 11:00 am, May 22
USGS
science for a changing world
Nanawale Estates
Kapoho
Pāhoa
Ponding Lava
PGV
Vacationland Hawaii
Leilani Estates
Flow front as of 7:37 am
Active Lava Channels
Pohoiki
Active Ocean Entry
Opihikao
Island of Hawai'i
Rift Zone
Summit
Kīlauea Volcano
Major road
Minor road
Path of steepest descent
Flows 5/3 - 5/21
Notable past lava flows
Puna Geothermal Venture
0 0.5 mi
0 0.5 Km
1840
1955
1960


Kilauea LERZ Fissure 20 - 22 May 2018, 00:22-00:41 UTC
×10^18
Leilani Estates
Malama St
Malama-Ki Forest Reserv
1 km
Latitude [deg]
Longitude [deg]
SO2 column [molec/cm2]
19.475
19.47
19.465
19.46
19.455
19.45
19.445
19.44
19.435
19.43
-154.94 -154.93 -154.92 -154.91 -154.9 -154.89 -154.88
18
16
14
12
10
8
6
4
2
0


USGS
Highway 132
F17
F22
F19
F06
Leilani Estates subdivision
some map distortion here
new flow
levee breach
Pohoiki Rd
Highway 137
ocean entry
22 May 2018, 06:45 am
Thermal map of fissure system
0 0.5 1 Miles
N



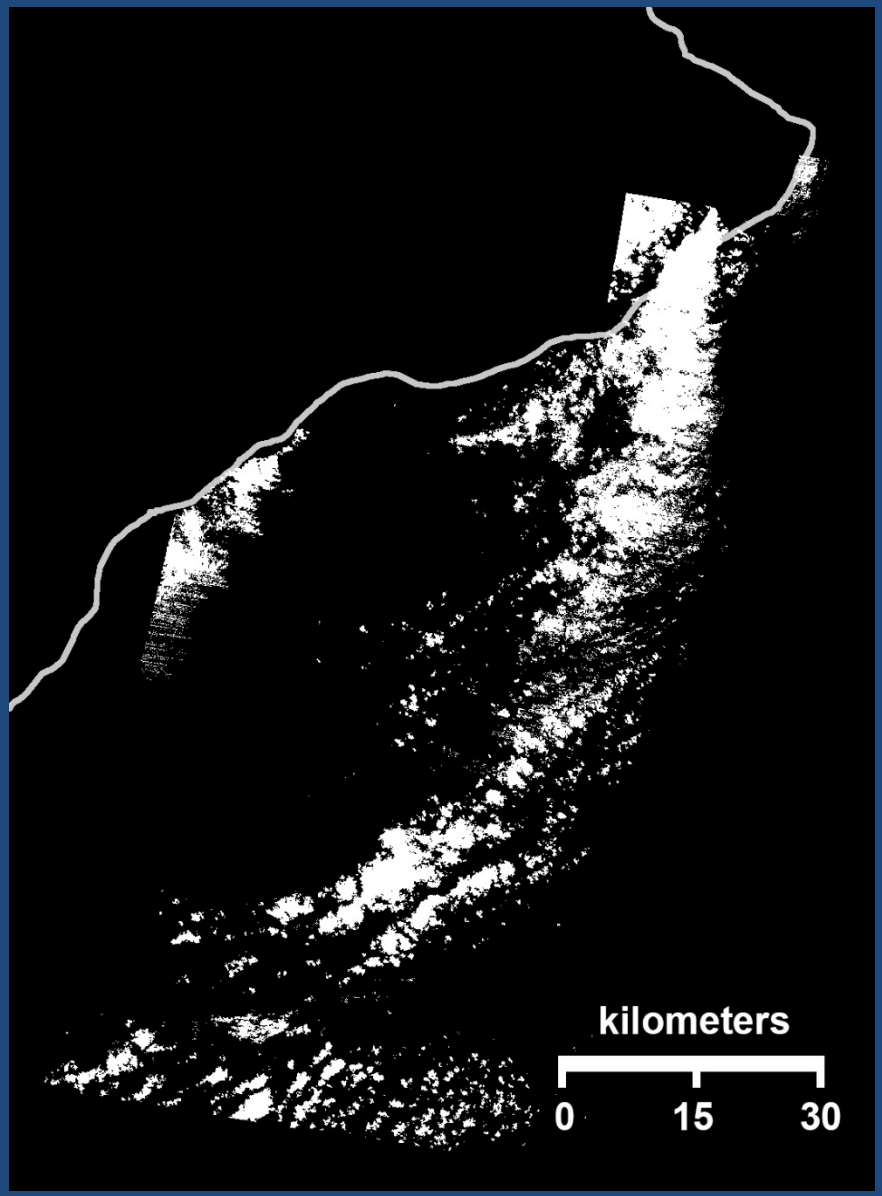


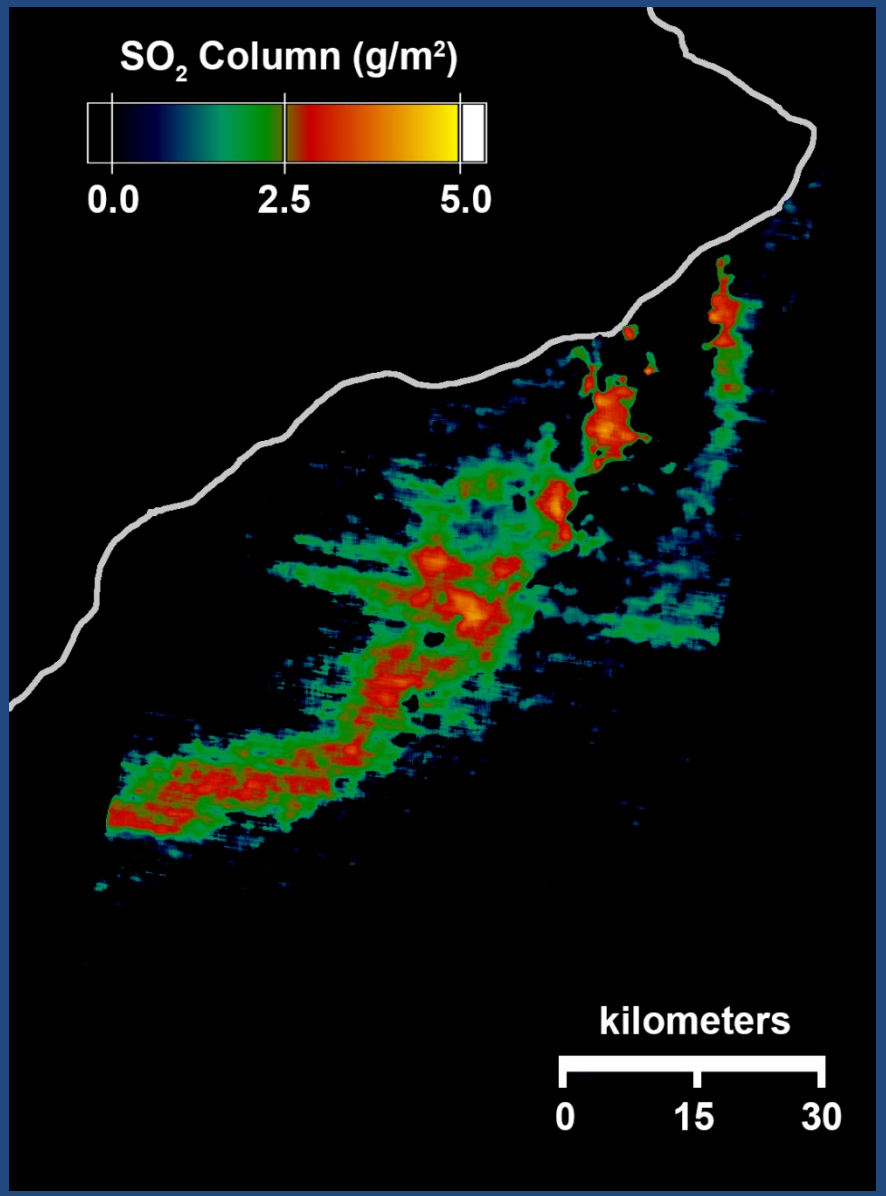
ASTER VNIR

2018-05-22

21:01 UTC

ASTER TIR

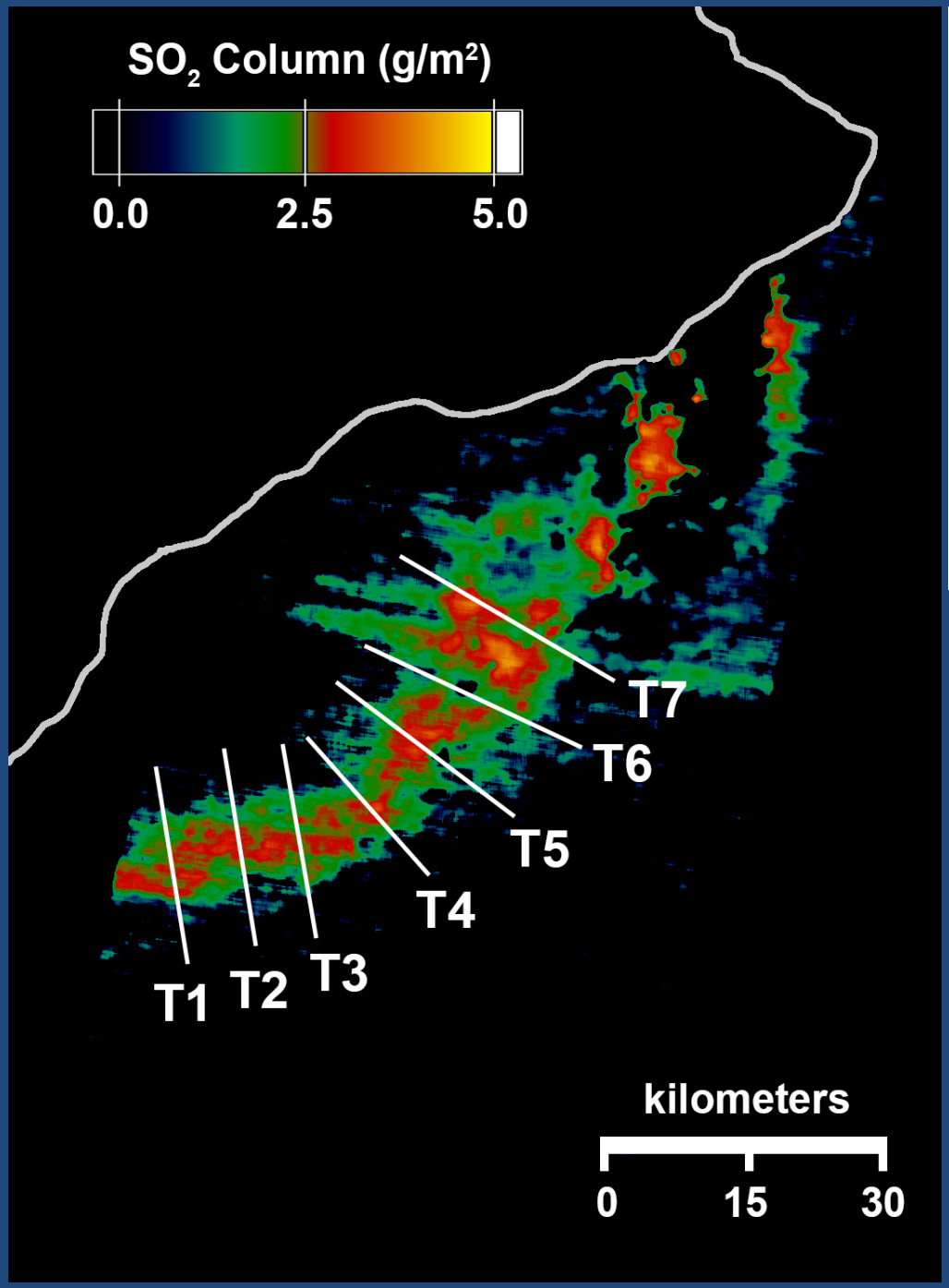


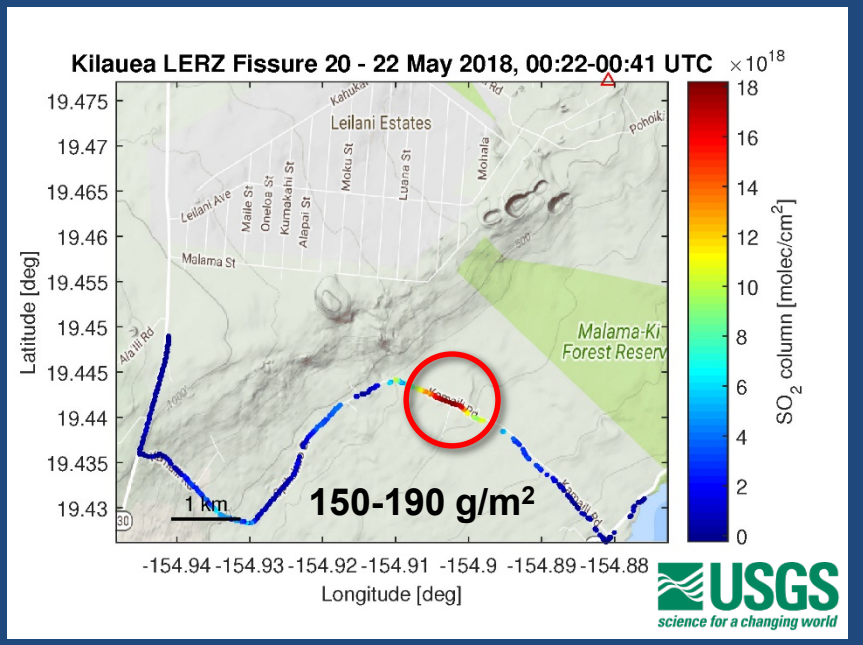


Cloud Mask

2018-05-22
21:01 UTC

SO_2 Column Density

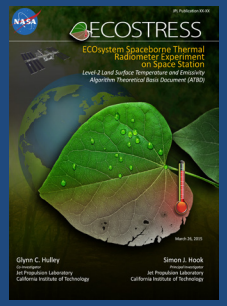




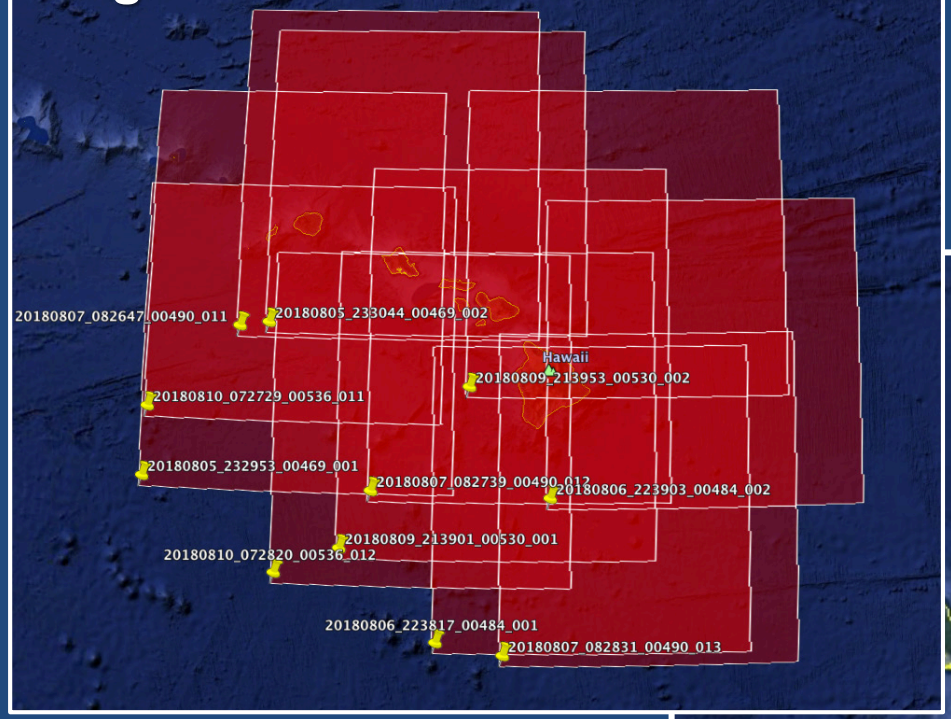
HVO Integrated Transects (kg/m)*	ASTER Integrated Transects (kg/m)
37.52	T1: 25.37
30.34	T2: 20.75
45.03	T3: 24.20
38.10	T4: 19.94
Ave: 37.75 ± 5.2	T5: 25.90
	T6: 23.98
	T7: 41.00
	Ave: 25.88 ± 6.5

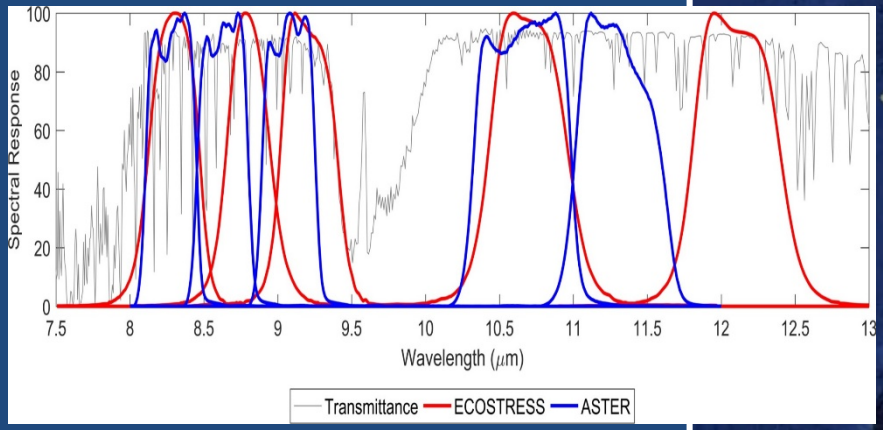
**USGS/HVO data analyses are preliminary, and not for distribution*

ECOSTRESS Deployment on ISS Affords Multiple Opportunities to Observe Hawaii!

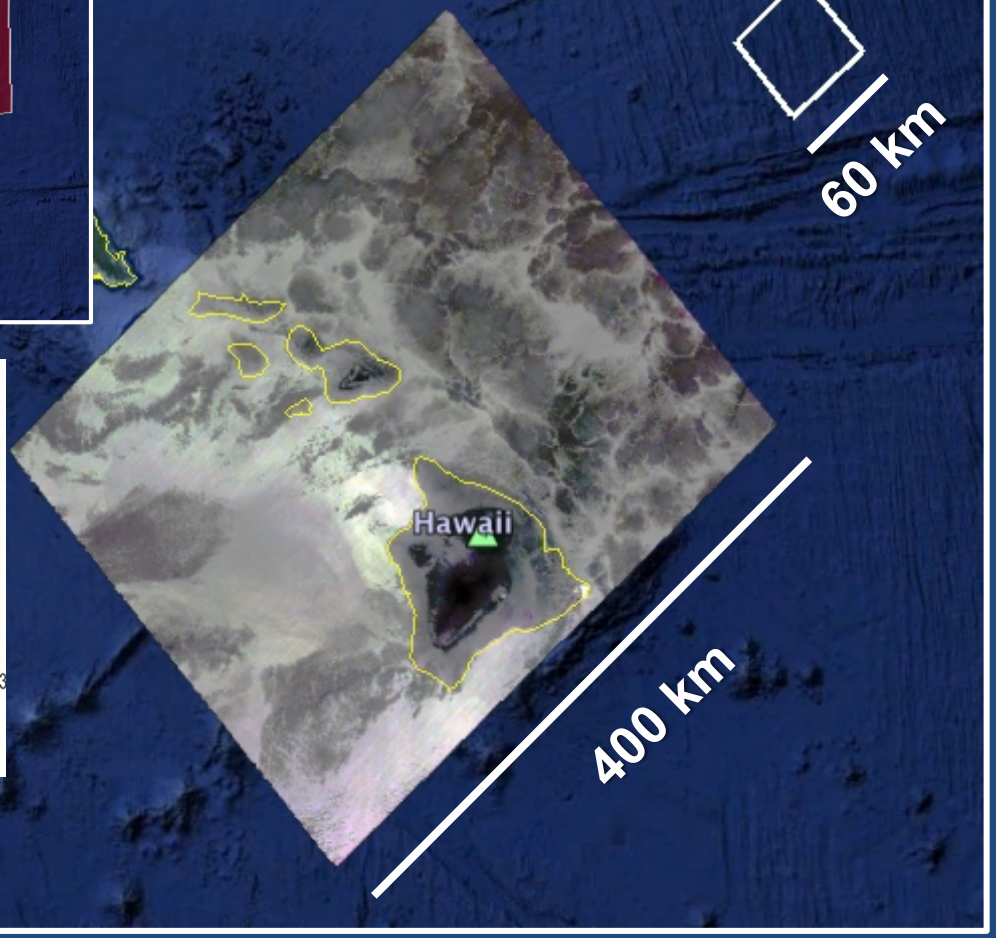


August 5 – 10: 11 Observations





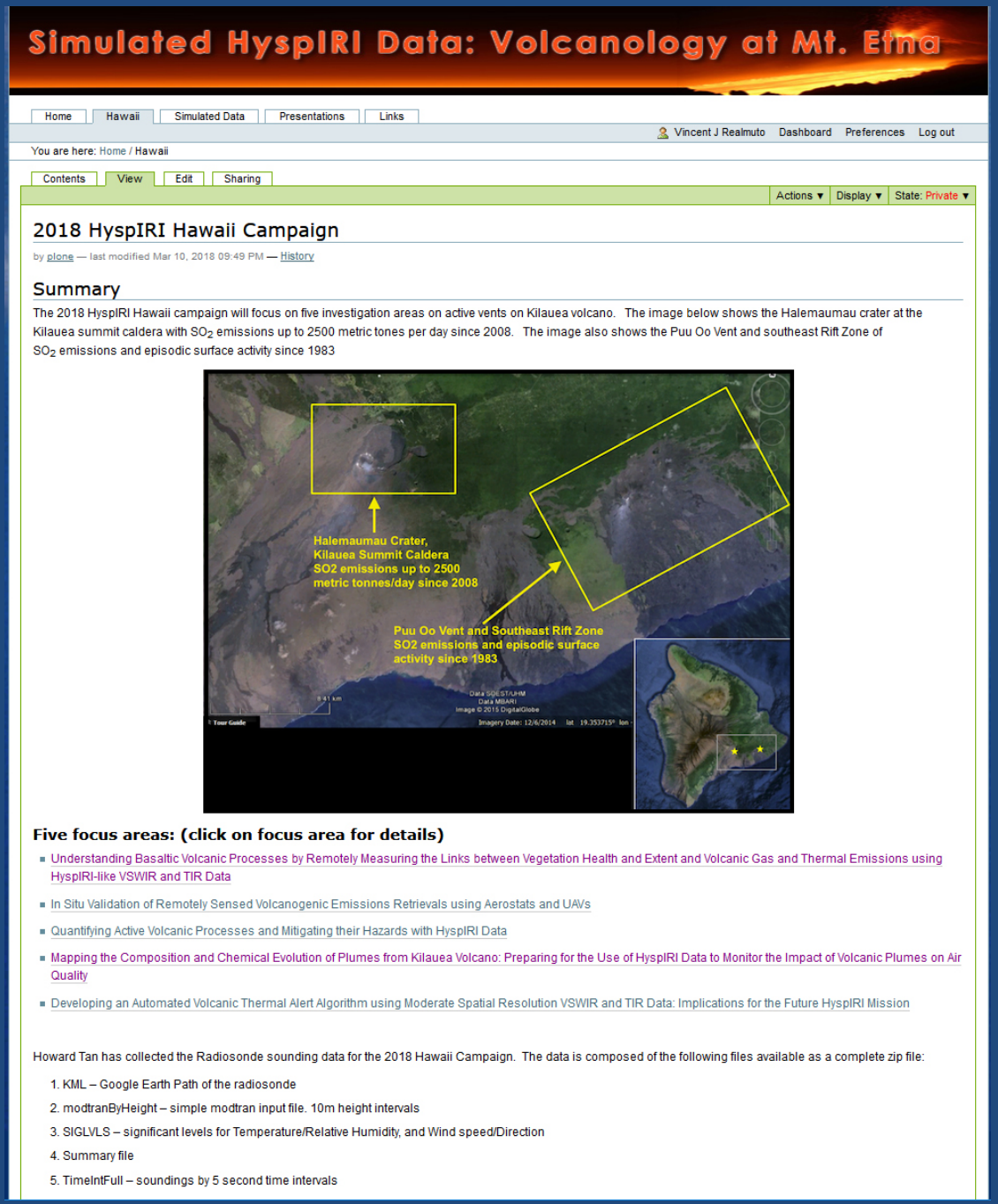
2018-08-07 08:27 UTC



Spatial Resolution	L1: 38 X 67 m L2: 70 X 70 m

HyspIRI-Hawaii Volcanology Website

- https://volcanology-hyspiri.jpl.nasa.gov
- Links to Archived AVIRIS, MASTER, and HyTES Data
- Repository for High-Level Data Products (e.g., radiosonde)
- Links to Current PI Investigations



Thank You for
Your Attention.